

Light on Cut Chrysanthemum: Measurement and Simulation of Crop Growth and Yield

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Abstract

The effects of plant density and light intensity on crop growth and yield of cut chrysanthemum were investigated experimentally and simulated with a generic explanatory crop growth model (HORTISIM). In winter, supplementary light (HPS; $48 \mu\text{mol m}^{-2} \text{s}^{-1}$ PAR) increased total incident PAR with 24%, whereas total dry matter production per m^2 was increased with 45%. The effect of supplementary light on plant dry and fresh mass, and number of flowers per plant at different plant densities (32, 48 or 64 m^{-2}), was larger at lower densities. In summer, a linear relationship between cumulative dry mass production and cumulative intercepted PAR was observed in each of three shading treatments. However, the slope of this line (light use efficiency) decreased with increasing light level being 4.1 g MJ^{-1} , 3.4 g MJ^{-1} and 2.7 g MJ^{-1} for 43%, 66% and 100% light, respectively. HORTISIM could accurately predict crop growth and yield at most light conditions, with measured climatic data, initial plant mass and time course of leaf area index being model inputs. However, in summer at 100% light the model strongly overestimated dry mass production.

INTRODUCTION

The use of supplementary assimilation light in cut chrysanthemum production is increasing in the Netherlands. Important questions are: what light levels should be used, when should the lights be turned on/off and what plant densities should be used under supplementary light. Crop growth models can play an important role in these decisions. However, models have mainly been developed for greenhouse vegetable crops, whereas the number of models for ornamental crops is very limited (Marcelis et al., 1998). The present work aimed at analysing and understanding the effects of plant density and light intensity on crop growth and yield of cut chrysanthemum. The concept of crop light use efficiency was evaluated, using a generic explanatory crop growth model HORTISIM (Gijzen et al., 1998). Data from greenhouse experiments were used in a preliminary validation of HORTISIM for cut chrysanthemum.

MATERIALS AND METHODS

Experimental Setup

Two experiments were conducted in compartments of a multispan Venlo-type glasshouse at Wageningen University, The Netherlands (lat. 52°N). Cuttings of chrysanthemum (*Dendranthema grandiflorum* Ramat. 'Reagan Improved'), rooted in peat cubes, were obtained from a commercial propagator (Fides, Maasland, The Netherlands), and planted on 12 January 2000 (Experiment 1) or 6 May 1999 (Experiment 2) in eight parallel soil beds (1.125 m wide and 10.25 m length per bed) per compartment. In Experiment 1, two levels of supplementary lighting (control; incandescent lamps, $3.5 \mu\text{mol m}^{-2} \text{s}^{-1}$ PAR or supplementary assimilation light, high pressure sodium (HPS) lamps, SON-T Agro, Philips, The Netherlands, $48 \mu\text{mol m}^{-2} \text{s}^{-1}$ PAR) and three plant densities ($32, 48$ or 64 plants m^{-2}) were applied. Light level was applied as main factor with one

repetition in two compartments, and randomised over the two halves inside each compartment and within a light level plant density was randomised (split-plot design). In Experiment 2, three light levels (100%, 66% and 43% obtained by white shading screens) were applied as main factor inside each of three compartments. Within each light level, three plant densities (32, 48 or 64 plants m⁻²) were randomised (split-plot design).

Long days (19 h in Experiment 1; 14-16 h natural daylength in Experiment 2) were applied for 3 weeks followed by short days (11 h; blackout screen and/or turn off lamps) until the end of the experiments. Lamps were on continuously during daytime in Experiment 1. Experiments stopped when the flowers had reached commercial maturity (about 75 days after planting). Temperature, CO₂ concentration and global radiation were recorded every 5 min by a commercial computer system (Hoogendoorn, Vlaardingen, The Netherlands). Average daily global radiation was 4.8 MJ m⁻² d⁻¹ for Experiment 1 and 18.9 MJ m⁻² d⁻¹ for Experiment 2. Average 24-h greenhouse temperature was 17.7°C in Experiment 1 and 21.2°C in Experiment 2. Average CO₂ concentration between 1000 to 1600 h was about 400 µmol mol⁻¹ in both experiments.

Plant Measurements and Analysis

Destructive measurements were carried out every 3 to 10 days. Samples were taken from 5 plants per experimental plot, excluding border plants (two rows on each side of a bed). Number of leaves (>10 mm) on the main stem, number of flowers (including buds), total leaf area (LI-COR Model 3100) and fresh and dry (105°C for 14 h in ventilated oven) mass of leaves (including petioles), stems and flowers were measured. No measurements on roots were conducted. Treatment effects in measured and calculated plant and crop parameters were determined by analysis of variance and means were separated by Student's *t*-test at 5% level.

Simulation of Crop Growth

A generic greenhouse climate and crop growth model HORTISIM (Gijzen et al., 1998) was used to simulate dry matter production in cut chrysanthemum. Potential crop growth and daily crop gross assimilation rate ($P_{gc,d}$) is computed by integration of leaf assimilation rates (maximum carboxylation velocity, $V_{cmax} = 100 \mu\text{mol m}^{-2} \text{s}^{-1}$, and maximum rate of electron transport $J_{max} = 200 \mu\text{mol m}^{-2} \text{s}^{-1}$ at 25°C) over total crop leaf area throughout the day. Crop growth results from $P_{gc,d}$ minus maintenance respiration rate (R_m), multiplied by the conversion efficiency. R_m is simulated as a function of relative growth rate, according to Heuvelink (1995). Measured hourly averages of global radiation outside, and temperature and CO₂ concentration inside the greenhouse were input to the model. A greenhouse transmissivity of 63% for diffuse radiation was estimated, based on measurements in a similar greenhouse compartment (Heuvelink et al., 1995). Observed leaf area index and dry matter partitioning to leaves, stems and flowers were also input to the model. Dry matter partitioning to the roots was assumed to be constant at 10%.

RESULTS

An increase of incident PAR with 24% using supplementary light gave rise to an increase in final total dry mass per m² with 45% (averaged over three plant densities; not shown). At 48 plants m⁻², supplementary light increased plant fresh and dry mass and the number of flowers per plant with about 40% (Table 1). The effect of supplementary light interacted with plant density for all three parameters, effects of light being larger at reduced plant density. For example, supplementary light increased plant dry mass by 4.8, 3.4 and 2.4 g, for plant densities of 32, 48 and 64 plants m⁻², respectively (Fig. 1).

Cut chrysanthemum dry mass growth was linearly related to intercepted PAR (Fig. 2). However, the different shading levels showed different light use efficiencies (LUE), 100% light resulting in a LUE of 2.7, whereas under heavy shade this was 4.1 g MJ⁻¹ PAR. HORTISIM also predicted a reduction in LUE with increased light intensities (Fig. 3). The model predicted crop growth in Experiment 1 (Fig. 4A) reasonably well. In

Experiment 2, crop growth was predicted quite well under heavy or light shade, whereas it was strongly overestimated for the non-shaded control (Fig. 4B).

DISCUSSION

Supplementary assimilation light improved cut chrysanthemum growth significantly (Table 1, Fig. 1). This agrees with Hughes and Cockshull (1972), who observed increased final plant dry mass with increased light (highest light level being $3.8 \text{ MJ m}^{-2} \text{ d}^{-1}$), as in Experiment 1 average incident PAR was increased from 1.5 to $1.8 \text{ MJ m}^{-2} \text{ d}^{-1}$ by the supplementary light. Total biomass production increased more than proportional with supplementary light, which can be explained by the importance of maintenance respiration (R_m) relative to crop gross assimilation rate ($P_{gc,d}$) under low light (winter). R_m is not affected by assimilation light. If R_m takes a large part, e.g. 50%, of $P_{gc,d}$, a proportional increase in $P_{gc,d}$ will result in a more than proportional increase in growth, which is proportional to $P_{gc,d}$ minus R_m . This relative large R_m at low light intensities also explains the strong increase in LUE between 0.5 and $2 \text{ MJ m}^{-2} \text{ d}^{-1}$ (Fig. 3).

Effects of supplementary light on plant parameters interacted with plant density (Fig. 1). This can be explained by an expected improved biomass production per m^2 under supplementary light, which is independent of plant density, as already most of the light is intercepted at all densities. This indeed was observed in Experiment 1. Hence, the same extra biomass per m^2 as a result of supplementary light, results in a larger absolute biomass increase per plant at lower densities. The number of flowers per plant responded in the same way, as it appeared to be closely correlated with total plant biomass (Heuvelink et al., 2000).

The linear relationship between crop growth and cumulative intercepted radiation observed for chrysanthemum at constant shade level (Fig. 2), has been reported by many authors for many crops (Monteith, 1994). Observed LUE under heavy shade in summer ($4.1 \text{ g MJ}^{-1} \text{ PAR}$) was equal to LUE in winter (Experiment 1; data not shown). This value agrees quite well with those reported by Challa et al. (1995) for tomato (about $3 \text{ g MJ}^{-1} \text{ PAR}$ incident on the crop) and by Kage et al. (2001) for cauliflower (3 to $4 \text{ g MJ}^{-1} \text{ PAR}$). Measurements clearly showed a decreased LUE in cut chrysanthemum grown under high light intensities compared to low light intensities. Such an effect is to be expected, based on light saturation of photosynthesis at leaf level, which is also reflected, although to a much lesser extent, at crop level. Furthermore, at increased light level the fraction direct light is higher, which is used less efficiently compared to diffuse radiation (Gijzen, 1992). Also Kage et al. (2001) observed a reduction in LUE with daily PAR for field-grown cauliflower crops. It seemed that the observed reduction in LUE at high light intensity in Experiment 2 was stronger than predicted by the model HORTISIM (Fig. 4B). This might mean that chrysanthemum has a lower light-saturated leaf photosynthetic rate than assumed in the model.

It is concluded that HORTISIM can be used to predict cut chrysanthemum growth and yield for decisions on supplementary light, however, more research is needed to investigate the overestimation of growth under high light in summer.

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Tables

Table 1. Effect of assimilation light (HPS, 48 $\mu\text{mol m}^{-2} \text{s}^{-1}$) on final cut chrysanthemum parameters and total incident and intercepted PAR (Photosynthetic Active Radiation, 400-700 nm). Plants were grown at a density of 48 plants m^{-2} (Experiment 1).

	Control	Assimilation light	LSD ^a
Fresh mass (g plant ⁻¹)	66.5	90.0	11.0
Dry mass (g plant ⁻¹)	7.9	11.3	1.7
Number of flowers per plant	13.8	19.6	3.7
Total incident PAR (MJ m ⁻²)	110	137	
Total intercepted PAR (MJ m ⁻²)	86	112	

^aLeast significant difference according to Student's *t*-test at $P=0.05$.

Figures

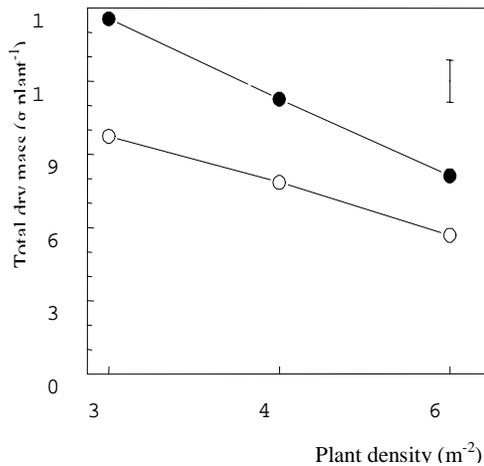


Fig. 1. Final plant dry mass as a function of plant density and light level (Experiment 1; O control, • supplementary assimilation light). Vertical bar indicates LSD at $P=0.05$.

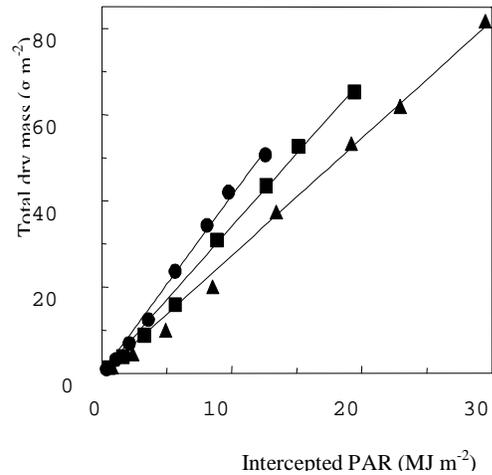


Fig. 2. Total dry mass as a function of accumulated intercepted PAR at 3 light levels (▲ 43%, ■ 66%, • 100%) averaged over 3 plant densities (Experiment 2). Symbols based on periodic destructive measurements during cultivation. Linear regression lines: ▲ $y=2.73x$, ■ $y=3.40x$, and • $y=4.12x$.

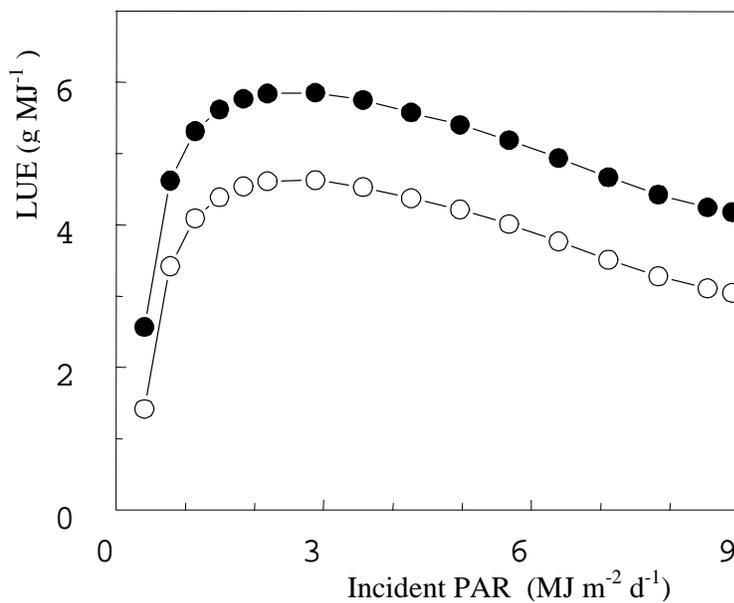


Fig. 3. Simulated (HORTISIM) LUE for a crop (total biomass 200 g m⁻²; leaf area index of 3), as a function of incident PAR at 20°C and a CO₂ concentration of (O) 350 or (•) 1000 μmol mol⁻¹. Variation in PAR was obtained by using a range of global radiation amounts as model input on day 147 of the year.

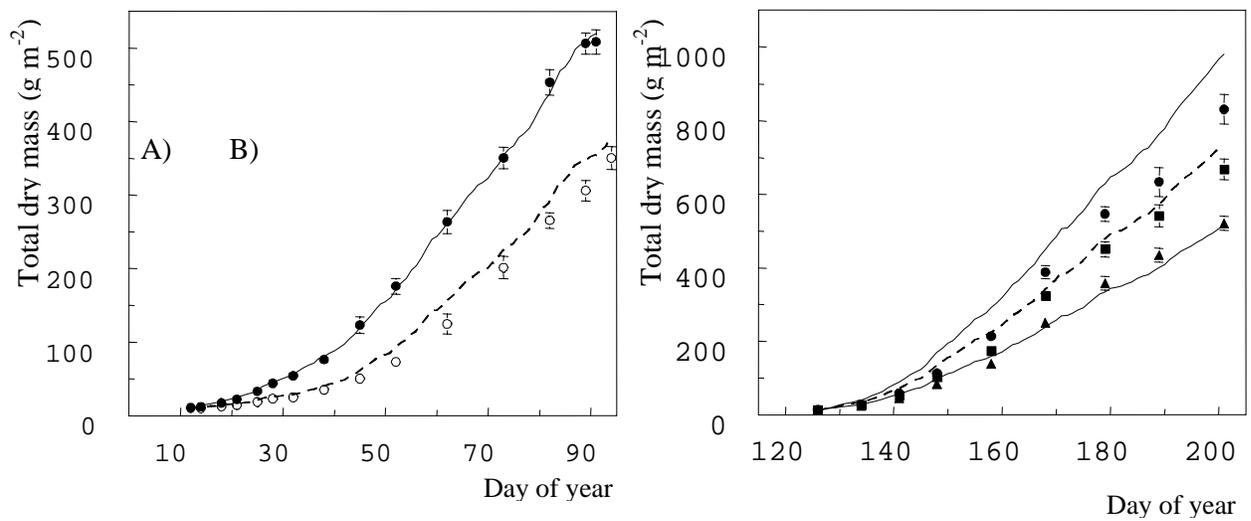


Fig. 4. Simulated (lines; HORTISIM) and measured (symbols) dry mass as a function of day of the year in (A) Experiment 1 at two light levels (O control, ● supplementary assimilation light) and (B) Experiment 2 at three light levels (▲ 43%, ■ 66%, ● 100%). Both graphs show averages over three plant densities (32, 48 and 64 plants m⁻²). Vertical bars indicate standard error of mean when larger than symbols.